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Form 1/77

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1 Please give the title of the invention: Expression systems

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Continuation sheets for this Patents Form 1/77			
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Expression systems

The present invention relates to new expressions systems, and in particular to expression systems in which a gene of interest is expressed at an optimal level. Particular examples of such expression systems are retroviral packaging cell lines and a number of preferred cell lines have been identified.

The ability of eukaryotic and prokaryotic ribosomes to reinitiate translation at an internal start codon within an mRNA sequence has previously been recognised. Studies have been reported in which the efficiency of the process, which is generally regarded as being low, has been connected with the length of the intercistronic sequence (Kozak (1987) Mol. Cell Biol. 7, 3438-3445). Selection of this sequence or spacer as 70bp in length, and containing no other start codons, has been previously reported as being optimal for reinitiation in a eukaryotic cell line (Cosset F-L., Virology (1991) 185, 862).

The applicants have found a way in which the inefficiency associated with the translation reinitiation process can be used to good effect.

According to the present invention there is provided a recombinant expression vector comprising a gene of interest and a selectable marker gene, wherein the selectable marker gene is arranged downstream of the gene of interest and a stop codon associated with the gene of interest is spaced from a start codon of said selectable marker gene at a distance which is sufficient to ensure that translation re-initiation is required before said selectable marker protein

is expressed from the corresponding mRNA.

The invention further provides a process for producing cell lines in which a gene of interest is expressed, which process comprises transforming host cells with an expression vector comprising said gene of interest and a selectable marker gene, wherein the selectable marker gene is arranged downstream of the gene of interest and a stop codon associated with the gene of interest is spaced from a start codon of said selectable marker gene at a distance which is sufficient to ensure that translation re-initiation is required before said selectable marker protein is expressed from the corresponding mRNA, and selecting those cells where expression of the selectable marker gene may be detected.

Since re-initiation of translation is a relatively inefficient process, this means that the selectable marker protein will be expressed at lower levels than the product of the gene of interest. When the marker protein is expressed at detectable levels, the gene of interest will be expressed at higher levels. This will ensure that during the subsequent selection procedure, only those cell clones which express the gene of interest at higher or optimal levels will survive. Low expressing clones will be eliminated by the selection process.

Cells transformed with the above-described expression vectors form a further aspect of the invention.

The host cells are suitably eukaryotic or prokaryotic host cells, preferably eukaryotic host cells.

The number of nucleotides in the space between the stop codon of the gene of interest and the start codon of the

selectable marker will suitably be in the range of from 20-200 nucleotides, preferably from 70-80 nucleotides.

The vectors used in the process of the invention may be any of the known types, for example expression plasmids or viral vectors.

Selected cells may be cultured and if required, the protein product of the gene of interest isolated from the culture using conventional techniques. Alternatively, expression of the gene of interest may result in other desired effects, for example, where the gene of interest is included as part of a viral packaging construct.

Some experimental and clinical gene transfer protocols require the design of gene transfer vectors suitable for *in vivo* gene delivery (Miller, A.D. 1992. Nature 357:455-460). Retroviral vectors are attractive candidates for such applications, because they can provide stable gene transfer and expression (Samarut J. et al.,Meth. Enzymol. in press) and because packaging cells have been designed which produce non-replication competent viruses (Miller A.D (1990) Hum Gene Ther. 1 5-14). However currently available recombinant retroviruses suffer from a number of drawbacks.

Packaging cell lines provide <u>in trans</u> the retroviral proteins encoded by the <u>gag</u>, <u>pol</u>, and <u>env</u> genes required to obtain infectious retroviral particles. The <u>gag</u> and <u>pol</u> products are respectively the structural components of the virion cores and the replication machinary (enzymes) of the retroviral particles whereas the <u>env</u> products are envelope proteins responsible for the host-range of the virions and for the initation of infection and for sensitivity to humoral factors. An ideal packaging cell line should

produce retroviruses that only contain the retroviral vector genome, and absolutely no replication-competent genomes c defective genomes encoding some of the viral structural genes.

A number of packaging cell lines designed for human gene transfer have been constructed in the past. The first of these used full length retroviral genomes that had been crippled for important cis-regulated replicative functions (reviewed in Miller, Hum. Gene Ther. 1: 5-14 1990). In order to reduce the possibility of occurrence of replication-competent viruses and of transfer of virus structural genes, a second generation of safer packaging cell lines has been designed by using two separate and complementary genomes which express either gag-pol or env and are packaging-deficient (Miller supra).

The cells into which these helper genomes were introduced were isolated by cotransfecting them with plasmids encoding selectable markers. However, as no selection was applied on the packaging-deficient retroviral genome itself, the helper functions can be lost during the passages of the cells in culture and the current packaging systems provide limited titers of infectious retroviral vectors, usually only of the order of 10^5-10^6 infectious units i.u/ml. Indeed the cotransfection with a plasmid encoding a selectable marker does not directly select the best gag-pol-env-expressing cells.

The invention further provides a retroviral packaging cell line comprising a host cell transformed with (i) a packaging deficient construct which expresses a viral gag-pol gene and a first selectable marker gene, and/or (ii) a packaging-deficient construct which expresses a viral env gene and a

second selectable marker gene; wherein a start codon of the first and second selectable markers are spaced from the stop codons of the viral gag-pol gene and the viral env gene respectively by a distance which ensures that reinitiation of mRNA translation is required for expression of marker protein product of said first and/or second selectable marker gene.

The retroviral packaging cell line may be obtained by the above described process which will involve selecting transfected cells which express said first and/or second marker genes.

By using helper constructs which are directly selectable and which provide for high expression of the viral gene, high titre retroviral vectors may be obtained.

Helper constructs for use in the process form a further aspect of the invention.

The retroviral vectors prepared from the conventional packaging cell lines are usually not contaminated by replication-competent retroviruses (RCRs). However, recombinant amphotropic murine retroviruses have been shown to arise spontaneously from certain packaging cell lines. The generation of such RCRs involves recombination at least between gag-pol/env packaging sequence and vector sequences (Cosset et al., Virology, (1993) 193:385-395).

Recombinant RCRs have been associated with the development of lymphomas in some severely immunosuppessed monkeys (Donahue et al., J. Exp Med (1992) 176: 1125-1135). In addition, retroviral vector preparations may also contain, at low frequencies, retroviruses coding for functional

envelope glycoproteins (Kozak and Kabat, 1990, J. Virol. 64: 3500-3508) or for gag-pol proteins. Although the pathogenicity of these gag-pol or env recombinant retroviruses is probably low, more evolved recombinant retroviruses with higher pathogenic potential may occur when injected in vivo, by recombination and/or complementation of the initial recombinant viruses with some endogenous retroviruses.

In a preferred embodiment of the retroviral packaging cell lines of the invention, the overlapping sequences between the genomes of the retroviral vector and the helper construct are reduced, for example as compared to constructs such as CRIPenv and CRIPAMgag (Danos et al., Proc. Natl. Acad. Sci USA 85: 6460-6464). In particular, the viral sequences in the helper construct are reduced, for example, not only the packaging sequence but also the 3' Long Terminal Repeat(LTR), the 3' non-coding sequence and/or the 5'LTR may be eliminated.

The possibility of generation of such RCRs and recombinant retroviruses can be reduced by reducing the overlapping sequences between the genomes of both the retroviral vector and the helper construct.

Conventional retroviral vectors are strongly inactivated by human serum which makes them of limited or no use for in situ gene transfer in gene therapy applications. It has previously been shown that inactivation by complement in human serum is controlled by the cell line used to produce the virions and by viral envelope determinants (Takeuchi et al., J. Virol (1994) 68:8001-8007). In particular, inactivation is caused by some properties of the cell lines that have been used to construct the packaging cells (NIH-

3T3) and also by viral determinants located in the retroviral envelope as shown (Takeuchi et al., J. Virol (1994) 68:8001-8007). In vivo gene delivery is an important goal for a number of human gene therapy strategies.

The applicants have found that certain cell lines form preferred packaging cell lines.

Particularly preferred packaging cell lines are the HT1080 line, the TE671 line, the 3T3 line, the 293 line and the Mv-1-Lu line. One example of retroviral packaging cells that will produce complement-resistant virus comprise human HT1080 cells packaging cells and express RD114 envelope. Such cells form a preferred aspect of the invention.

Packaging cell lines according to the invention provide 50-100 fold increased titers of retroviral vectors as compared to conventional packaging cell lines. Retroviral vectors provided by these new cells are safe, in terms of generation of RCRs, and considerably more resistant to inactivation by human complement.

Packaging cell lines according to the invention may be able to transduce helper-free, human complement-resistant retroviral vectors at titers consistently higher than 10^7 i.u./ml.

Suitable semi-packaging cell lines in accordance with the invention are those which express only the gag-pol genes. Such cell lines may suitably be derived from TE671, MINK Mv-1-Lu, HT1080, 293 or NIH-3T3 cells by introduction of plasmid CeB (the MoMLV gag-pol expression unit).

Particularly preferred expression vectors in accordance with

the invention for use in retroviral packaging cell lines are those which include MLV gag and pol genes such as CeB. Other plasmids may include gag and pol genes from other retroviruses or chimeric or mutated gag and pol genes.

Various viral and retroviral envelope genes may be included in the plasmids such as MLV-A envelope, GALV envelope, VSV-G protein, BaEV envelope, RD114 envelope and chimeric or mutated envelopes. Plasmids which include the RD114 env gene such as FBdelPRDSAF as illustrated hereinafter, provide one example of suitable constructs.

The novel retroviral packaging cells described hereinafter, have been designated FLY cells, and may be designed for in vivo gene delivery.

Considerable variations were found between the various cell lines screened for their ability to release type C mammalian retroviruses. In addition, few cell lines were able to produce retroviruses completely resistant to human complement. Based on these two criteria, human fibrosarcoma HT1080 and rhabdomyosarcoma TE671 cells were selected for optimum construction of packaging cells.

Other studies have shown the importance of endogenous retrovirus expression in the generation of recombinant retroviruses from retroviral packaging lines (Ronfort et al., Virology, (1995), 207, 271-275, Vanin, E.F.et al., J Virol (1994) 68:4241-4250.). The co-packaging of an endogenous genome and a vector can lead to emergence of recombinant retroviruses (Vanin et al., supra). Recombination involves template switching during reverse transcription of such hybrid retroviruses (Hu et al., Science, (1990) 250:1227) and homologies between the two

genomes considerably enhance the frequency of reverse transcriptase jumps (Zhang et al., J. Virol. (1994) 68: 2409-2414). Therefore an ideal packaging cell line should not express endogenous MLV-like (or type C retrovirus-like) retroviral genomes which can be packaged by type C gag proteins (Scadden et al., J. Virol. (1990) 64: 424-427, Torrent et al., J. Mol. Biol. (1994) 240 434-444).

Expression of type C retroviruses in HT1080 or TE671 cells could not be detected by PCR analysis using generic primers (Shih et al., J. Virol. (1989) 63: 64-75), suggesting that HT1080- and TE671 derived packaging cells may be safer in this respect than those generated from NIH3T3 cells, which are known to express and package sequences related to type C retroviruses (Scadden et al., supra).

To generate the FLY packaging cell lines, HT1080 cells were transfected with gag-pol and env expression plasmids designed to optimise viral protein expression. Direct selection for viral gene expression was achieved in accordance with the invention by expression of a selectable marker gene by re-initiation of translation of the mRNA expressing the viral proteins. This strategy resulted in packaging cell lines capable of producing extremely high titer viruses. Furthermore, long-term expression of packaging functions can be maintained in these cells. Many unnecessary viral sequences were eliminated from the packaging constructs to reduce the risk of helper virus generation; indeed the final packaging cells did not produce helper virus, in that no replication competent virus (RCR) could be detected per 10^7 vector particles.

The FLY packaging cells described herein are safer than, for example, psiCRIP cells, at least for generation of env

recombinant retroviruses as is illustrated in Table 4 hereinafter, probably because less retroviral sequences overlapping with the vector were present in the present expression plasmid. Few reports have addressed the question of the characterization of recombinant retroviruses (RVs) (Cosset, F.L., et al., Virology (1993) 193:385-395). It is possible that such RVs could not be detected in previous packaging cell lines due to lower overall titers. RVs are defective in normal cell culture conditions but are likely to evolve to replication competent viruses if they are allowed to replicate in cells complementing their expression like co-cultivated packaging cells (Bestwick et al., Proc. Natl Acad Sci USA, (1988) 85: 5404-5408, Cosset et al., (1993) supra).

In preferred retroviral packaging systems according to the invention, RVs are eradicated for example by removal of viral LTRs from the packaging construct.

Consistent with our previous studies (Takeuchi, Y., et al., J Virol (1994) 68:8001-8007), LacZ(RD114) and lacZ(MLV-A) pseudotypes produced from HT1080 and TE671cells were more resistant to human complement than LacZ(RD114) or LacZ(MLV-A) pseudotypes produced by 3T3 of dog cells. It was therefore decided to use RD114 and MLV-A env genes to generate recombinant virions with MoMLV cores.

The sequence of RD114 env gene was determined and is shown in Figure 4. It was found to be very close to BaEV (baboon endogenous virus) a type C retrovirus (Benveniste, R.E.et al., Proc. Natl. Acad. Sci. USA (1973) 70:3316-3320; Kato, S.et al., Japan. J. Genet. (1987) 62:127-137) with an envelope gene displaying similarities to the external part of type D simian retroviruses (SRVs). RD114 uses the SRV

receptor on human cells (Sommerfelt & Weiss, Virology (1990) 176:58-69; Sommerfelt, M.A. et al., J Virol (1990) 64:6214-6220) making the FLY packaging cells with RD114 envelope capable of generating virions with different tropism. Retroviral vectors prepared so far for human gene therapy have used either MLV-A or GALV (gibbon ape leukemia virus) envelopes which display some similarities (Battini, J.L.,et al., J Virol. (1992) 66:1468-1475) and which use two related cell surface receptors for infection (Miller, D.G. et al., J Virol (1994) 68:8270-8276). Differences in tissue-specific expression of MLV-A or GALV receptors have been reported (Kavanaugh et al., Proc Natl Acad Sci USA (1994) 91:7071-7075).

The invention will now be particularly described by way of example with reference to the accompanying drawings in which:

Figure 1.illustrates the structure and expression of CeB. The env gene (XbaI-ClaI) of plasmid pCRIP was removed and was replaced by coinsertion of the two fragments XbaI-SfiI (restriction sites underlined) from pOXEnv and a SfiI-ClaI PCR product containing the bsr selectable marker. This results in positioning the bsr start codon (shadowed) 74 bp downstream to the pol stop codon (bold).

Open triangle are start codons (gag and bsr), black triangles are stop codons (pol and bsr). The shadowed triangle is the start codon of env, in the same reading frame with that of bsr. SD and SA are the splice donnor and splice acceptor sites.

Figure 2 illustrates the structure and expression of FbdelPASAF.

Immediately after the stop codon of env (bold) was inserted a non retroviral KasI-NcoI (restriction sites underlined) linker which positions the phleo start codon (shadowed) 7 bp downstream.
Open triangle are start codons (env and phleo), black triangles are stop codons (env and phleo). SD and SA are the splice donnor and splice acceptor sites.

Figure 3 illustrates plasmids for expression of Ampho, Eco, RD114, Xeno, 10A1, GALV, VSV-G and FeLVB envelopes.
All genes are expressed in the same backbone as detailed in fig. 2. The BglII sites for ecotropic (MoMLV strain), 10A1, xenotropic (NZB.1.V6 strain) and amphotropic (4070A strain), the NdeI site of RD114 (SC3C strain, the BamHI site for both FeLVB and GALV were used as 5' ends, and linked to MscI site immediately after the splice donor site in the leader of FB29 LTR.

Figure 4 shows the sequence of the RD114 env gene (SEQ D No 1).

The components of the viral particles are produced by two independent expression plasmids (gag-pol or env) which also contain selectable markers (bsr or phleo) expressed from the same transcriptional units as gag-pol or env (figs. 1& 2). The selectable markers are located downstream to gag-pol or env genes and there is an optimal distance between the stop codon of the upstream reading frames and the start codon of the selectable genes that should allow re-initiation of translation (Kozak, Mol Cell Biol. (1987) 7,:3438-3445). Because there is no "Kozak" sequence (Kozak, Cell,(1986) 44: 283-292) required for a normal initiation of translation for the marker gene, they can only be expressed by re-initiation of translation after the upstream viral gene has been

successfully expressed. Consequently and also because re-initiation of translation is a poorly efficient process, after transfection of these plasmids, cells resistant to the drugs corresponding to those selectable genes express high levels of the viral proteins.

To avoid viral transmission of these "helper" genomes the constructs used suitably have the classical deletions of both the packaging sequence located in the leader region and of the 3'LTR, the latter being replaced by SV40 polyadenylation sequences (Figs 1 & 2).

Plasmid CeB is the MoMLV gag-pol-expression unit. It derives from pCRIP, a plasmid used to generate the constructs introduced in the CRIP and CRE packaging cell lines (Danos and Mulligan, 1988). As shown in fig. 1 for generation of plasmid CeB the env gene of pCRIP has been deleted mostly and the bsr selectable marker, -encoding a protein conferring resistance to blasticidin (Izumi et al., Experimental Cell Research (1991) 197, 229-233)- has been inserted downstream to pol gene. There are exactly 74 bp with no ATG triplets between the stop codon of pol and the start codon of bsr, this allows its expression by re-initiation of translation on the gag-pol mRNA, after translation of the gag-pol reading frame.

FbdelPASAF is a plasmid expressing the amphotropic env gene and the phleo selectable marker conferring resistance to phleomycin (Gatignol et al., FEBS Letters (1988) 230:171-175). By using a PCR-mediated mutagenesis strategy which modifies the end of env gene (see fig. 2), a 76 bp linker was inserted between the stop codon of env and the start codon of phleo. This allows expression of phleo from the env mRNA by re-initiation of translation. In addition

compared to known env-expressing constructs, this strategy of construction has reduced the length of sequences overlapping with the ends of conventional retroviral vectors. The env genes of Mo-MLV, FeLVB, NZB.1V6, 10A1, GALV and RD114 are expressed by plasmids FBdelPMoSAF, FBdelPBSAF, FBdelXSAF, FBdelpGSAF, FBdelp10A1SALF and FBdelPRDSAF, respectively, by using the same backbone as FBdelPASAF (fig. 3). Retroviral vectors produced with the RD114 envelope will be useful for in vivo gene delivery as comparatively to MLV ecotropic or amphotropic envelopes, virions pseudotyped with RD114 envelopes are not inactivated by human complement when they are produced by Mink Mv-1-Lu cells or by some human cells (Table 1).

The HT1080 cell line, isolated from a human fibrosarcoma (ATCC CCL121). The TE671 cell line isolated from a human rhabdomyosarcoma (ATCC CRL 8805)(purchased from ATCC, and tested for absence of usual cell culture contaminants by ECACC), has been used for the definitive construction of packaging cell lines. HT1080 line was chosen among a panel of primate and human lines because MLV-A and RD114 efficiently rescued retroviral vectors from these cells and also because RD114 pseudotypes produced by this cell line were stable when incubated in human serum. In a standard assay (Takeuchi et al., J Virol (1994), 68, 8001-8007), these latter viruses were found more than 500 fold more stable than similar pseudotypes produced in 3T3 cells.

Another advantage for the use of non murine cells to derive packaging lines is the absence of MLV-related endogenous retroviral-like sequences (like VL30 in 3T3 cells) that can cross-package with MLV-derived retroviral vectors (Torrent et al., 1994) and generate potentially harmful recombinant retroviruses.

The helper constructs were introduced into other cell lines (HT1080 (table 2) Mink Mv-1-Lu (table 2), 3T3 (not shown), TE671 (table 2)) for the purpose of comparisons of the efficiency of the constructs.

As illustrated hereinafter (Table 2), the reverse transcriptase (RT) activity (provided by expression of the pol gene) in cells transfected with CeB is significantly higher than that of the same cells transfected by the parental plasmid pCRIP or that of cells chronically infected by MLV. This enhancement of viral gene expression is correlated with the titers of lacZ retroviral vectors when an envelope is provided in CeB-lacZ cells after comparison with titers of lacZ pseudotypes of either replication-competent viruses or other helper-free packaging systems.

For the generation of final packaging cell lines, the best clonal env transfectants have been selected. Packaging systems obtained in this way will be able to produce helper-free retroviral vectors at titers greater than 10^8 infectious particles per ml, which would be 10-100 fold higher to helper-free preparations of others.

Because of the way the selectable markers are expressed (see above), growing the packaging cells in phleomycin and blasticidin selective pressure increase and stabilize the expression of the retroviral components and particularly the envelopes, as it is possible that env glycoproteins have toxic effects for the producer cells in the long term which may lead to a decrease of expression.

Such an enhancement of viral production observed with the packaging systems described herein might increase the emergence of unwanted retroviruses having recombined between

the genomes of both the retroviral vector and either of the two packaging-deficient constructs. However, the constr have been designed in such a way that it reduces the probability of emergence of recombinant viruses compared to the parental constructs. To check their safety, attempts have been made to detect the presence of replication-competent retroviruses by a mobilisation assay of a lacZ provirus. No RC viruses have been found in all retroviral vector preparations tested so far.

The following Examples illustrate the invention.

Example 1

Preparation of Cell lines and viruses.

The following cell lines were used:

A204 (ATCC HTB 82), HeLa (ATCC CCL2), HT1080 (ATCC CCL121), MRC5 (ATCC CCL171), T24 (ATCC HTB 4), VERO (ATCC CCL81) and D17 (ATCC CCL183) were purchased from ATCC.

HOS, TE671 and Mv-1-Lu cells and their clones harboring MFGnlslacZ retroviral vector as described by Takeuchi et al., J Virol (1994), 68, 8001-8007.

The above cell lines were grown in DMEM (Gibco-BRL, U.K.) supplemented with 10% fetal calf serum.

EB8 (Battini et al., J. Virol (1992) 66: 1468-1475);
psiCRE, psiCRELLZ and psiCRIP (Danos et al., Proc. Natl. Acad. Sci USA (1988) 85: 6460-6464);
Cells GP+EAM12 (Markowitz et al., Virology (1988), 167, 400-406); and
NIH-3T3 murine fibroblasts.

These cell lines were grown in DMEM (GIBCO-BRL, U.K.) supplemented with 10% new-born calf serum.

Mv-1-Lu, TE671 and HT1080 cells were transfected using calcium-phosphate precipitation method (Sambrook et., "Molecular Cloning" 1989, Cold Spring Harbour Laboratory Press: New York) as described elsewhere (Battini et al., supra). CeB-transfected Mv-1-Lu, TE671 and HT1080 cells were selected with 3, 6-8 and 4 μg/ml of blasticidin S (ICN, UK), respectively, and blasticidin-resistant colonies were isolated 2-3 weeks later. Cells transfected with the various env-expression plasmids were selected with phleomycin (CAYLA, France): 50 μg/ml (for FBASALF-transfected cells) or 10 μg/ml (for FBASAF-, FbdelPASAF-, FbdelPMOSAF, FBdelPIOAISAF or FBdelPRDSAF-transfected cells). Phleomycin-resistant colonies were isolated 2-3 weeks later.

Production of lacZ pseudotypes using replication competent viruses, amphotropic murine leukemia virus (MLV-A) 1504 strain and cat endogenous virus RD114, was carried out as described previously (Takeuchi et al., J Virol (1994), 68, 8001-8007).

Example 2

Preparation of Plasmids.

The env gene of pCRIP (Danos et al., supra) was excised by HpaI/ClaI digestion. A 500 bp PCR-generated DNA fragment was obtained using pSV2-bsr (Izumi et al., Experimental Cell Research (1991), 197, 299-233) as template and a pair of oligonucleotides:

(5'>CGGAATTCGGATCCGAGCTCGGCCCAGCCGGCCACCATGAAAACATTTAACATTTC TC) (SEQ ID NO 2) at 5' end and

(5'>GATCCATCGATAAGCTTGGTGGTAAAACTTTT) (SEQ ID No 3) at 3' end, with SfiI and ClaI sites, respectively. This fragment

was inserted in HpaI/ClaI sites of pCRIP by co-ligation with a 85 bp HpaI/SfiI DNA fragment isolated from pOXEnv (Rus et al., Nucleic Acids Research (1993), 21, 1081-1085) wh provides the end of the Moloney murine leukemia virus (MoMLV) pol gene. The resulting plasmid named CeB (Fig. 1) could express the MoMLV gag-pol gene as well as the bsr selectable marker conferring resistance to blasticidin S, both driven by the MoMLV 5'LTR promoter.

A series of env-expression plasmids was generated using the 4070A MLV (amphotropic) env gene (Ott et al., J Virol (1990), 64, 757-766) and the FB29 Friend MLV promoter (Perryman et al., Nucleic Acid Res (1991), 19, 6950). In FBASALF (Fig. 1) a BglII/ClaI fragment containing the env gene was cloned in BamHI/ClaI sites of plasmid FB3LPh which also contained the C57 Friend MLV LTR driving the expression of the phleo selection marker. A 136 bp env fragment was generated by PCR using plasmid FB3 (Heard et al., J Virol (1991), 65, 4026-4032) as template and a pair of oligonucleotides: (5'>GCTCTTCGGACCCTGCATTC) (SEQ ID NO 4) at 5' end (before ClaI site) and (5'>TAGCATGGCGCCCTATGGCTCGTACTCTATAGGC)(SEQ ID NO 5)at 3' end, providing a KasI restriction site immediately after the env stop codon. This PCR fragment was digested using ClaI and KasI. A DNA fragment containing the FB29 LTR and the MLV-A env gene was obtained by NdeI/ClaI digestion of FBASALF. The fragments were co-ligated in NdeI/KasI digested pUT626 (kindly provided by Daniel Drocourt, CAYLA labs, France). In the resulting plasmid, named FBASAF (Fig. 1), the phleo selectable marker was expressed from the same mRNA as the env gene. A BglII restriction site was created after the MscI site at position 214 in the FB29 leader by using a commercial linker (Biolabs, France). A NdeI/BglII fragment containing the FB29 LTR was co-inserted with the BglII/ClaI

env fragment in NdeI/ClaI-digested FBASAF plasmid DNA, resulting in plasmid FBdelPASAF (Fig. 1). Compared to FBASAF, FBdelPASAF has a 100bp larger deletion in the leader region.

Example 3

Cloning and Sequencing of the RD114 env gene

The RD114 env gene was first sub-cloned in plasmid Bluescript KS+ (Stratagene) as a 3 Kb HindIII insert isolated from SC3C, an RD114 infectious DNA clone (Reeves et al., J. Virol (1984), 52, 164-171). A 2.7 kb ScaI-Hind III fragment of this subclone containing the RD114 env gene was sequenced (Figure 4 (SEQ ID NO 1)- EMBL accession number; X87829). The 5' non-coding sequence upstream of an NdeI site was deleted by an EcoRI/NdeI digestion followed by filling-in with Klenow enzyme and self-ligation. From this plasmid, two DNA fragments were obtained: a BamHI/NcoI 2.5 Kb fragment and a 63 bp PCR-generated DNA fragment using (5'>CGCCTCATGGCCTTCATTAA) (SEQ OD NO 6) at 5' end (before NotI site) and (5'>TAGCATGGCGCCTCAATCCTGAGCTTCTTCC) (SEQ ID NO 7) at 3' end, providing a KasI restriction site just after RD114 env gene stop codon. The PCR fragment was digested with NcoI and KasI. Both fragments were co-inserted between BglII and KasI sites of FBdelPASAF and the resulting plasmid was named FBdelPRDSAF (Fig. 1).

Plasmid pCRIPAMgag- (Danos, O. et al., Proc Natl Acad Sci USA (1988) 85:6460-6464) was used for transfection.

Example 4

Infection assays.

Target cells were seeded in 24-multiwell plates ($4x10^4$ cells per well) and were incubated overnight. Infections were then

carried out at 37°C by plating 1 ml dilutions of viral supernatants in the presence of 4 μg/ml polybrene (Sigma) target cells. 3h later virus-containing medium was replac by fresh medium and infected cells were incubated for two days before X-gal staining, performed as previously described (Tailor et al., J Virol (1993), 67, 6737-6741, Takeuchi et al., J Virol (1994), 68, 8001-8007). Viral titers were determined by counting lacZ-positive colonies as previously described (Cosset et al., J. Virol. (1990) 64: 1070-1078). Stability of lacZ pseudotypes in fresh human serum was examined by titrating surviving virus after incubation in 1:1 mixture of virus harvest in serum-free medium and fresh human serum for 1 h at 37°C as described before (Takeuchi et al. supra).

Example 5

Reverse transcriptase (RT) assay.

RT assays were performed either as described previously (Takeuchi et al. supra) or using an RT assay kit (Boehringer Mannheim, U.K.) following the manufacturer's instruction but using $MnCl_2$ (2 mM) instead of $MgCl_2$.

Example 6

Screening producer cell lines.

Viral particles generated with RD114 envelopes have been found to be more stable in human serum than virions with MLV-A envelopes and that the producer cell line also controls sensitivity (Takeuchi et al. supra). A panel of cell lines was screened for their ability to produce high titer viruses and for the sensitivity of these virions to human serum. To do this, cells were infected at high multiplicity with lacZ pseudotypes of either MLV-A or RD114

and cells producing helper-positive lacZ pseudotypes were established. Human HT1080 and TE671 and mink Mv-1-Lu cells were found to release high titer lacZ(RD114) and lacZ(MLV-A) viruses. LacZ(MLV-A) pseudotypes produced by HT1080 cells were more resistant to human serum than those produced by other cells. The titer of these viruses was only four-fold less following a 1 hr incubation with human serum than a control incubation (Table 1). LacZ(RD114) pseudotypes produced by human cells or mink Mv-1-Lu cells were in general stable in human serum (Table 1). These results suggested that HT1080, TE671 and Mv-1-Lu cells provided the best combination of high lacZ titers and resistance to human serum and they were therefore used for the generation of retroviral packaging cells.

Table 1. Titer and stability of lacZ pseudotypes.

Producer cell	LacZ(MLV-A)		LacZ(RD114)	
	Titer[a]	Stability[b]	Titer[a]	Stability[b]
A204	650	<3	1,200	105
HeLa	9	nd	2,000	115
HOS	4,500	6	23,000	86
HT1080	2,000,000	26	400,000	129
MRC-5	450	10	1,000	nd
T24	350	nd	1,200	nd
TE671	15,000	2	90,000	38
VERO	260	nd	90	nd
D17	900	<1	200,000	1
Mv-1-Lu	80,000	1	200,000	120

a: titration on TE671 cells as lacZ i.u./ml
b: % of infectivity of human serum-treated viruses compa to fetal calf serum-treated viruses

Example 7
Construction of an improved gag-pol expression vector.

A MoMLV gag-pol expression plasmid, CeB (Fig. 1), was derived from pCRIP (Danos et al., Proc. Natl. Acad Aci USA (1988) 85: 6460-6464). Approximately 2 Kb of env sequence were removed from pCRIP and the bsr selectable marker, conferring resistance to blasticidin S (Izumi et al., Experimental Cell Research (1991) 197:229-233), was inserted 74 nts downstream of the gag-pol gene. This 74 nts interval had no ATG triplets and was thought to provide an optimal distance between the stop codon of the pol reading frame and the start codon of the bsr gene to allow re-initiation of translation (Kozak Mol Cell Biol., 1987, 7: 3438-3445). There was no "Kozak" consensus sequence (Kozak Cell, (1986) 44: 283-292) at the 5' end of the marker gene. Therefore, bsr could only be expressed by re-initiation of translation after the upstream gag-pol gene had been expressed. Consequently, after transfection of CeB in Mv-1-Lu/MFGnlsLacZ (ML), TE671/MFGnlsLacZ (TEL) or HT1080 cells, blasticidin S-resistant bulk populations and most cell clones expressed high levels of gag-pol proteins assessed by the reverse-transcriptase (RT) activity found in cell supernatants (Table 2). Considerably higher RT activities were found in bulk populations of CeB-transfected ML cells compared to bulk population of ML cells stably transfected with the parental pCRIP construct. Similarly the RT activities of two packaging cell lines generated using pCRIPenv- construct, psiCRE cells (Danos et al., supra) and

EB8 cells (Battini supra.) were less than that of CeB transfected clones (Table 2). Finally, RT activitiy in CeB transfected cell supernatants was higher than that of cells chronically infected by replication-competent MLV-A (Table 2).

Table 2. Secreted reverse transcriptase expression

Cell[a]	RT activity[b]	LacZ Titer[c]
ML/MLV-A	1	$8x10^4$
MLSvB	0.1	<1
MLCRIP (bulk)	0.15	nd
MLCeB (bulk)	1.7	nd
MLCeB1	4.2	$1x10^6$
MLCeB4	1.6	$1x10^6$
TEL/MLV-A	3.6	$2x10^6$
TELCeB6	5.2	$4x10^7$
HT1080/MLV-A	1.1	$1x10^6$
HTCeB6	1.9	$1x10^6$
HTCeB18	2.7	$2x10^6$
HTCeB22 (FLY)	6.9	$5x10^6$
HTCeB48	5.5	$3x10^6$
EB8	0.22	$1x10^4$
psiCRE-LLZ	1.2	$1x10^{5d}$

a: ML, Mv-1-Lu cells harboring a MFGnlslacZ provirus; TEL, TE671 cells harboring a MFGnlslacZ provirus; /MLV-A, cells chronically infected with MLV-A 1504 strain; MLSvB, ML cells transfected with a plasmid pSV2bsr alone; MLCRIP, ML cells co-transfected with pCRIP and pSV2bsr.

b: Average of arbitrary units relative to ML/MLV-A RT activity of at least two independent experiments was shown. The standard errors did not exceed 20 % of the values.

c: titration on TE671 cells as lacZ i.u./ml. After polyclonal transfection of a plasmid which expresses MLV-env in MLCeB clones, TELCeB clones, HTCeB clones and EB8 cells; nd, not done.

d: titration on NIH3T3 cells

To rescue infectious lacZ viruses, MLCeB and TELCeB clones were transfected with FBASALF DNA, a plasmid designed to express the MLV-A env gene (Fig. 1). Bulk populations of stable FBASALF transfectants were isolated and supernatants were titrated using TE671 cells as targets. Titers of lacZ viruses were higher than either MLV-A infected ML or TEL cells, or FBASALF-transfected EB8 cells (Table 2). These data suggested that CeB was an extremely efficient MLV gag-pol expression vector in mink Mv-1-Lu and TE671 cells. CeB was therefore used to derive packaging cells by transfection of HT1080 cells. 41/49 blasticidin S-resistant colonies had detectable levels of RT; 9 had RT activity higher than that of control MLV-A-infected HT1080 cells (data not shown). Expression of gag precursor was confirmed in cell lysates and supernatants of these 9 HTCeB clones by immunoblotting using antibodies against p30-CA (data not shown). The 4 clones with the highest expression of gag proteins (clones 6,18,22 and 48) were infected at high-multiplicity with helper free, lacZ pseudotypes bearing MLV-A envelopes (MFGnlslacZ(A)) produced by TELCeB6/FBASALF (Table 3) and then transfected with FBASALF. Supernatants of bulk, phleomycin-resistant transfectants were assessed for RT activity and lacZ titer (Table 2). Clone HTCeB22, named FLY, was found to be the best gag-pol producer clone and was used to introduce env expression vectors for the generation of packaging cell lines.

Table 3. Titer following env construct transfection

Producer cell	Env source	Titer[a]
psiCRIP lacZ 5	pCRIPAMgag-	$6x10^{4}$[b]
GP+EAM12 lacZ 25	envAM	$3x10^{5}$[b]
TELCeB6	FBASALF[c]	$5x10^{7}$
	FBASAF[c]	$2x10^{7}$
	FbdelPASAF[c]	$2x10^{7}$
TELCeB6	FBdelPASAF 1	$3x10^{7}$
	FbdelPASAF 4	$2x10^{7}$
	FbdelPASAF 6	$1x10^{7}$
	FbdelPASAF 7	$5x10^{7}$
	FbdelPASAF 8	$1x10^{7}$
	FbdelPRDSAF 2	$1x10^{6}$
	FbdelPRDSAF 4	$3x10^{5}$
	FbdelPRDSAF 7	$1x10^{7}$
	FbdelPRDSAF 8	$2x10^{6}$
FLY[d]	FBdelPASAF 1	$1x10^{1}$
	FbdelPASAF 4	$1.5x10^{6}$
	FbdelPASAF 5	$1x10^{6}$
	FbdelPASAF 7	$1x10^{6}$
	FbdelPASAF 13	$7x10^{6}$
	FbdelPASAF 14	$4x10^{6}$
	FbdelPASAF 15	$1x10^{6}$
	FbdelPASAF 16	$5x10^{6}$
	FbdelPASAF 17	$6x10^{6}$
FLYA4 lacZ 3	FBdelPASAF 4	$2x10^{7}$[b]
FLY[d]	FBdelPRDSAF 1	$2.5x10^{6}$
	FbdelPRDSAF 2	$1x10^{7}$
	FbdelPRDSAF 6	$5x10^{6}$
	FbdelPRDSAF 10	$2x10^{6}$
	FbdelPRDSAF 11	$3x10^{6}$
	FbdelPRDSAF 13	$1x10^{6}$
	FbdelPRDSAF 17	$5x10^{6}$
	FbdelPRDSAF 18	$3x10^{7}$
	FbdelPRDSAF 19	$6x10^{6}$

Average titers of at least three independent experiments were shown. The standard errors did not exceed 30 % of the titer values.

a: titrated on TE671 cells as lacZ i.u./ml
b: results of best MFGnlslacZ producer clones.
c: bulk populations of env-transfectants in TELCeB6 cells
d: titration after bulk infection with helper-free MFGnlslacZ.

Example 8
Construction of env expression vectors.

A series of MLV-A env expression plasmids were then generated (Fig. 1). In FBASALF, the env gene was inserted between two Friend-MLV LTRs, its expression driven by the FB29 MLV LTR (Perryman et al., supra). Most of the packaging signal located in the leader region was deleted. This plasmid also expressed the phleo selectable marker (Gatignol et al., supra) driven by the 3' LTR. FBASAF and FBdelPASAF were then designed following the same strategy used for CeB. These two vectors differed only by the extent of deletion of the packaging signal, FBdelPASAF having virtually no leader sequence. Compared to pCRIPAMgag- and pCRIPgag-2 env plasmids expressed in psiCRIP or psiCRE packaging cells (Danos et al., supra) about 5 Kb of gag-pol sequences was removed. In addition the 258 bp retroviral sequence containing the end of env gene and the begining of U3 found in pCRIPAMgag- and pCRIPgag-2 was also removed. For both FBASAF and FBdelPASAF plasmids, the phleo selectable marker was inserted downstream of the env gene by positioning a 76 nts linker with no ATG codons between the two open-reading frames. Phleo could therefore only be expressed by re-initiation of translation by the same ribosomal unit that had expressed the upstream env open reading frame. FBdelPASAF was also used to generate FBdelPRDSAF, an RD114 envelope expression plasmid (Fig. 1).

After transfection of the env plasmids into TELCeB6 cells (Table 2), bulk populations of phleomycin-resistant colonies were isolated and their production of lacZ virus measured (Table 3). FBASALF gave a titer of $5x10^7$ lacZ-i.u./ml, whilst titers with either FBASAF or FBdelPASAF were $2x10^7$ lacZ-i.u./ml (Table 3). Titers of $5x10^7$ or 10^7 lacZ-i.u./ml could be obtained with some FBdelPASAF cell clones or FBdelPRDSAF clones, respectively.

As FBdelPASAF has minimal virus-derived sequences and was shown to be the safest construct (see below and Table 4), it and FBdelPRDSAF were used to generate packaging lines from FLY cells (clone HTCeB22, Table 2). Envelope expression of these clones was assayed by interference to challenge with MFGnlslacZ(A) or MFGnlslacZ(RD) pseudotypes produced by TELCeB6/FBdelPASAF-7 or TELCeB6/FBdelPRDSAF-7, respectively (Table 3). The cell lines showing most interference were cross-infected at high multiplicity with these pseudotypes to provide MFGnlslacZ proviruses, and supernatants were then titrated on TE671 cells (Table 3). FLY-FBdelPASAF-13 (FLYA13 packaging line) and FLY-FBdelPRDSAF-18 (FLYRD18 packaging line) gave the highest productions of lacZ viruses, around 10^7 lacZ-i.u./ml. The best MFGnlslacZ producer clones derived from either psiCRIP cells (Danos et al., supra) or GP+EAM12 cells (Markowitz et al., supra) gave approximately 50 fold lower titers (Table 3). The lacZ titers of the FLY-derived lines shown in Table 3 are lower than the best TELCeB6-derived lines after transfection of either FBdelPASAF or FBdelPRDSAF (Table 3). However it should be noted that the lacZ provirus expressed in TELCeB6 cells was obtained after clonal selection but was introduced polyclonally in FLY-derived env-transfected cell clones. When FLY-FBdelPASAF-4 cells (FLYA4 packaging line), infected with helper-free MFGnlslacZ(RD), were cloned by limiting dilution the best

clones (eg. FLYA4lacZ3) were found to produce 20 times more infectious viruses than the bulk population, reaching th range of titers obtained with the best TELCeB6-FBdelPASA1 clones (Table 3).

Example 9

Assays for transfer of gag-pol or env functions.

To assay for replication-competent viruses, supernatants were used to infect TEL cells (a clone of TE671 cells harboring an MFGnlslacZ provirus). Infected cells were passaged for 6 days or longer and their supernatants were used for infection of fresh TE671 cells. No transmission of lacZ viruses could be detected (Table 4), demonstrating that the supernatants of pCRIPAMgag--, FBASALF-, FBASAF-, or FBdelPASAF-transfected TELCeB6 cells were helper-free. Similar absence of replication competent recombinant retroviruses was demonstrated using supernatant from a clone of psiCRIP-MFGnlslacZ cells or from two clones of FLYA-MFGnlslacZ cells (Table 4).

There have been reports that helper-free retroviral vector stocks may nevertheless contain recombinant retroviruses (replication incompetent) carrying either gag-pol or env genes (Bestwick et al., Proc Natl Acad Sci USA (1988), 85, 5404-5408, Cosset et al., Virology (1993), 193, 385-395, Girod et al., Virology (1995), in press). To assay for such recombinant retroviruses, mobilisation of an MFGnlslacZ provirus from two indicator cell lines which could cross-complement potential recombinant viruses carrying either gag-pol or env functional genes was attempted. The TELCeB6 line (Table 2) expressing gag-pol proteins was used as indicator cell line to test for the presence of env recombinant (ER) viruses. The TELMOSAF indicator line

expressing MoMLV env glycoproteins (obtained by transfection of FBMOSAF, a plasmid expressing the MoMLV env gene using FBASAF backbone, in TEL cells) was used to detect the presence of gag-pol recombinant retroviruses (GPR viruses). After passaging 4-8 days, the supernatants of the infected indicator cells were used to infect either human TE671 cells or murine NIH3T3 cells.

TELCeB6 cells transfected with various env-expressing constructs, pCRIPAMgag-, FBASAF and FBdelPASAF were compared. Although the supernatants of TELCeB6-FBdelPASAF cells were devoid of replication-competent retroviruses, they were found sporadically to transfer gag-pol genomes (Table 4). No GPR viruses could be detected when less than $2x10^5$ virions were used to infect the indicator cells. Similarly TELCeB6 indicator cells infected with various helper-free viruses were shown sporadically to release lacZ virions (Table 4). The number depended both on the env-expression vector used and on the virus input quantity. Compared to lacZ viruses generated using pCRIPAMgag- plasmid, the frequency of detection of the env-recombinant viruses was lower for supernatants generated by using FBASAF and FBdelPASAF constructs (Table 4). For FBdelPASAF construct when less than $5x10^5$ MFGnlslacZ(A) helper-free virions were used to infect the indicator cells, no ER retroviruses could be detected. From these experiments, it could be estimated that a supernatant, produced from TELCeB6-FBdelPASAF cells, containing $1x10^7$ infectious units of MFGnlslacZ retroviral vector contained no replication-competent virus, and about 100 gag-pol and 100 env recombinant retroviruses.

Table 4. Transfer of packaging function

Producer cell	Indicator cell	Input virus[a] (lacZ-i.u.)	Detectio ++	+	-
		Replication competent virus			
psiCRIP lacZ 5	TEL	$2x10^4$	0/4	0/4	4/4
TELCeB6-pCRIPAMgag-	TEL	$5x10^6$	0/4	0/4	4/4
TELCeB6-FBASAF	TEL	$5x10^6$	0/4	0/4	4/4
TELCeB6-FBdelPASAF	TEL	$5x10^6$	0/4	0/4	4/4
FLYA4 lacZ 3	TEL	$1x10^7$	0/4	0/4	4/4
FLYA4 lacZ 7	TEL	$1x10^7$	0/4	0/4	4/4
		Gag-pol recombinant			
TELCeB6-FBdelPASAF 7	TELMOSAF	$2x10^7$	0/4	1/4	3/4
TELCeB6-FBdelPASAF 7	TELMOSAF	$2x10^6$	0/4	2/4	2/4
TELCeB6-FBdelPASAF 7	TELMOSAF	$2x10^5$	0/4	2/4	2/4
TELCeB6-FBdelPASAF 7	TELMOSAF	$2x10^4$	0/4	0/4	4/4
		Env recombinent			
TELCeB6-pCRIPAMgag-	TELCeB6	$5x10^6$	2/4	1/4	1/4
TELCeB6-pCRIPAMgag-	TELCeB6	$5x10^5$	1/4	1/4	2/4
TELCeB6-pCRIPAMgag-	TELCeB6	$5x10^4$	0/4	2/4	2/4
TELCeB6-FBASAF	TELCeB6	$5x10^6$	0/4	2/4	2/4
TELCeB6-FBASAF	TELCeB6	$5x10^5$	0/4	1/4	3/4
TELCeB6-FBASAF	TELCeB6	$5x10^4$	0/4	1/4	3/4
TELCeB6-FBdelPASAF	TELCeB6	$5x10^6$	0/4	1/4	3/4
TELCeB6-FBdelPASAF	TELCeB6	$5x10^5$	1/4	3/4	0/4
TELCeB6-FBdelPASAF	TELCeB6	$5x10^4$	0/4	0/4	4/4

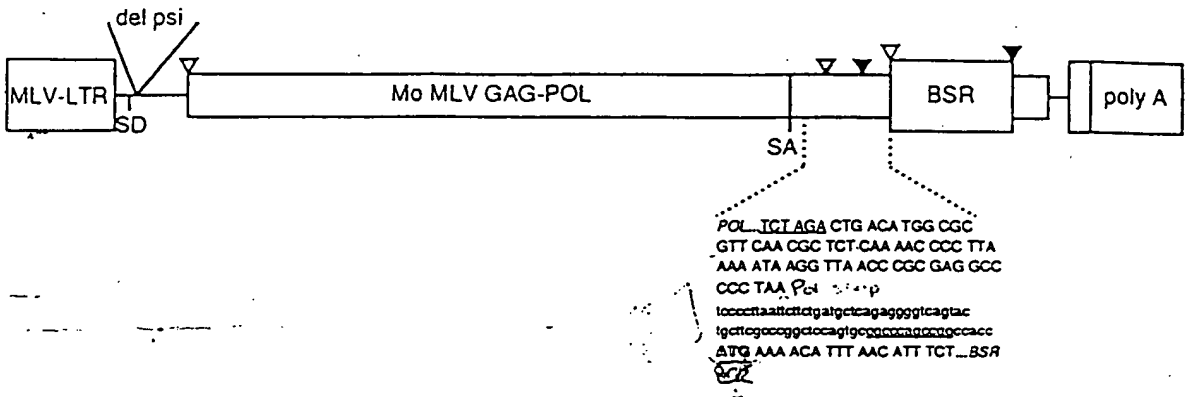
a: number of lacZ i.u. used to infect indicator cells

b: number of incidence out of four experiments. The ranges of lacZ titers rescued from infected indicator cells are shown for each virus input: >100 lacZ i.u./ml (++), 1-100 lacZ i.u./ml (+) and <1 lacZ i.u./ml (-).

Titers were determined on TE671 cells for replication competent virus and env recombinant and NIH3T3 cells for gag-pol recombinant.

Example 10

In order to confirm resistance to complement and absence of replication competent virus in our best packaging lines, MFGnlslacZ(A) and (RD) harvested from FLYA13 and FLYRD18, respectively, after polyclonal transduction of MFGnlslacZ (Table 3 above) were tested for stability in fresh human serum and generation of replication competent virus. Titers of MFGnlslacZ(RD) from FLYRD18 after 1 hr incubation with 3 independent samples of fresh human serum were 80 to 120 % of control incubations, while titers of MFGnlslacZ(A) from FLYA13 were 50 to 90 % of controls (data not shown). No replication competent virus was detected in the same assay described above (Table 4) when 1 x 10^7 i.u. each of MFGnlslacZ(A) and (RD) were tested.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Mo MLV GAG-POL
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BSR
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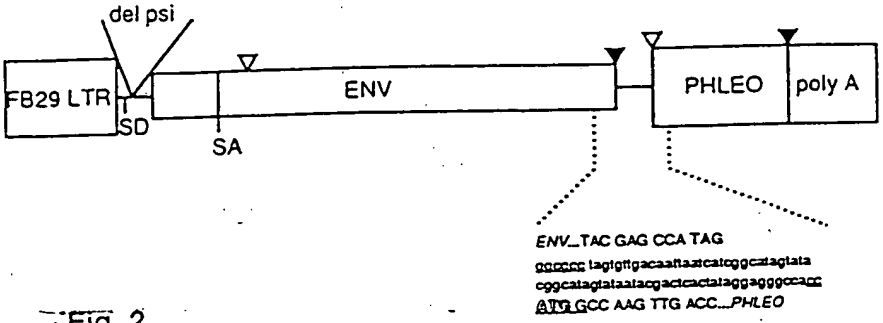
Fig. 1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PHLEO
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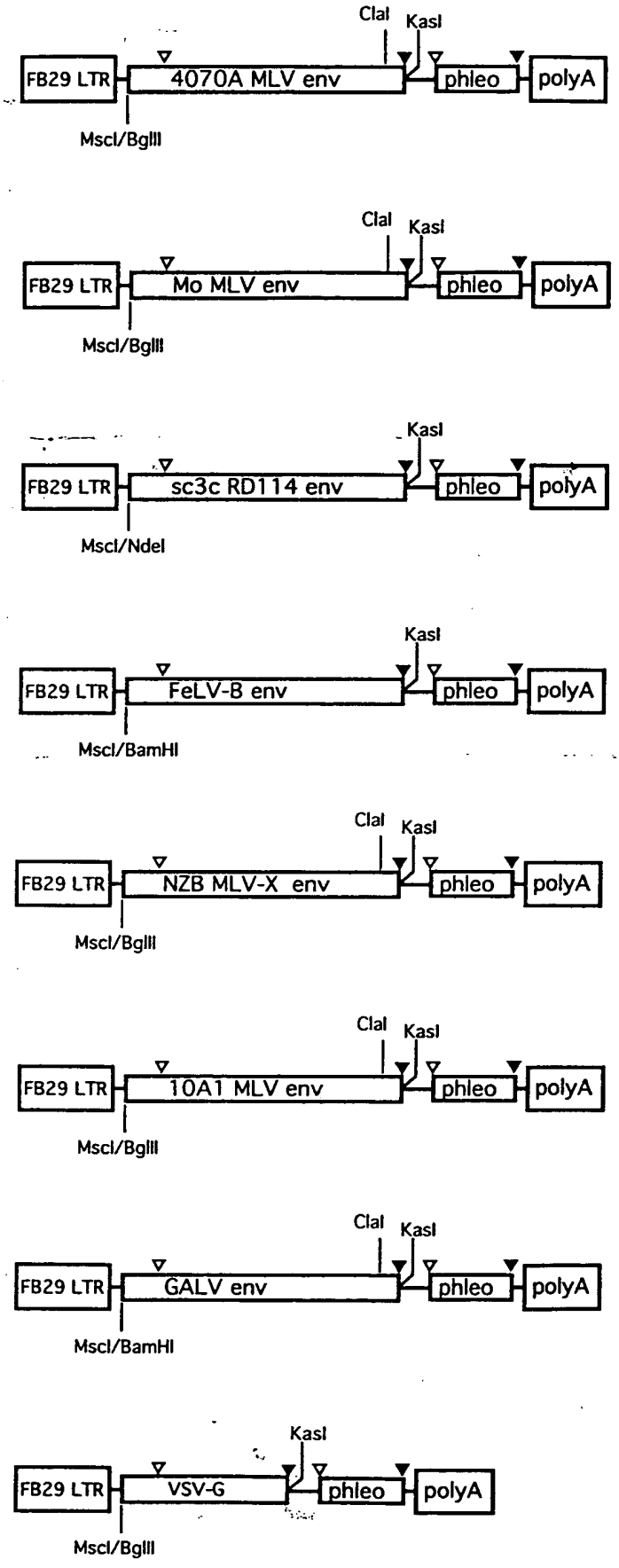
ATG GCC AAG TTG ACC...PHLEO

Fig. 2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polyA
MscI/BglII
KasI
FB29 LTR
sc3c RD114 env
phleo
polyA
MscI/NdeI
KasI
FB29 LTR
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ClaI
KasI
FB29 LTR
10A1 MLV env
phleo
polyA
MscI/BglII
ClaI
KasI
FB29 LTR
GALV env
phleo
polyA
MscI/BamHI
KasI
FB29 LTR
VSV-G
phleo
polyA
MscI/BglII

Fig.3

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CCCAAAATGAAACTCCCAACAGGAATGGTCATTTTATGTAGCCTAATAATAGTTCGGGCA 660
GGGTTTGACGACCCCCGCAAGGCTATCGCATTAGTACAAAAACAACATGGTAAACCATGC 720
GAATGCAGCGGAGGGCAGGTATCCGAGGCCCCACCGAACTCCATCCAACAGGTAACTTGC 780
CCAGGCAAGACGGCCTACTTAATGACCAACCAAAAATGGAAATGCAGAGTCACTCCAAAA 840
ATCTCACCTAGCGGGGGAGAACTCCAGAACTGCCCCTGTAACACTTTCCAGGACTCGATG 900
CACAGTTCTTGTTATACTGAATACCGGCAATGCAGGCGAATTAATAAGACATACTACACG 960
GCCACCTTGCTTAAAATACGGTCTGGGAGCCTCAACGAGGTACAGATATTACAAAACCCC 1020
AATCAGCTCCTACAGTCCCCTTGTAGGGGCTCTATAAATCAGCCCGTTTGCTGGAGTGCC 1080
ACAGCCCCCATCCATATCTCCGATGGTGGAGGACCCCTCGATACTAAGAGAGTGTGGACA 1140
GTCCAAAAAAGGCTAGAACAAATTCATAAGGCTATGACTCCTGAACTTCAATACCACCCC 1200
TTAGCCCTGCCCAAAGTCAGAGATGACCTTAGCCTTGATGCACGGACTTTTGATATCCTG 1260
AATACCACTTTTAGGTTACTCCAGATGTCCAATTTTAGCCTTGCCCAAGATTGTTGGCTC 1320
TGTTTAAAACTAGGTACCCCTACCCCTCTTGCGATACCCACTCCCTCTTTAACCTACTCC 1380
CTAGCAGACTCCCTAGCGAATGCCTCCTGTCAGATTATACCTCCCCTCTTGGTTCAACCG 1440
ATGCAGTTCTCCAACTCGTCCTGTTTATCTTCCCCTTTCATTAACGATACGGAACAAATA 1500
GACTTAGGTGCAGTCACCTTTACTAACTGCACCTCTGTAGCCAATGTCAGTAGTCCTTTA 1560
TGTGCCCTAAACGGGTCAGTCTTCCTCTGTGGAAATAACATGGCATACACCTATTTACCC 1620
CAAAACTGGACCAGACTTTGCGTCCAAGCCTCCCTCCTCCCCGACATTGACATCAACCCG 1680
GGGGATGAGCCAGTCCCCATTCCTGCCATTGATCATTATATACATAGACCTAAACGAGCT 1740
GTACAGTTCATCCCTTTACTAGCTGGACTGGGAATCACCGCAGCATTCACCACCGGAGCT 1800
ACAGGCCTAGGTGTCTCCGTCACCCAGTATACAAAATTATCCCATCAGTTAATATCTGAT 1860
GTCCAAGTCTTATCCGGTACCATACAAGATTTACAAGACCAGGTAGACTCGTTAGCTGAA 1920
GTAGTTCTCCAAAATAGGAGGGGACTGGACCTACTAACGGCAGAACAAGGAGGAATTTGT 1980
TTAGCCTTACAAGAAAAATGCTGTTTTTATGCTAACAAGTCAGGAATTGTGAGAAACAAA 2040
ATAAGAACCCTACAAGAAGAATTACAAAAACGCAGGGAAAGCCTGGCAACCAACCCTCTC 2100
TGGACCGGGCTGCAGGGCTTTCTTCCGTACCTCCTACCTCTCCTGGGACCCCTACTCACC 2160
CTCCTACTCATACTAACCATTGGGCCATGCGTTTTCAGTCGCCTCATGGCCTTCATTAAT 2220
GATAGACTTAATGTTGTACATGCCATGGTGCTGGCCCAGCAATACCAAGCACTCAAAGCT 2280
GAGGAAGAAGCTCAGGATTGAGCTTCCGGGACAAAAGCAGGGGGGAATGAGAAGTCAGAA 2340
CCCCCCACCTTTGCTACATAAATAACCGCTTTCATTTCGCTTCTGTAAAACGCTTATGCG 2400
CCCCACCCTAGCCGGAAAGTCCCCAGCCGCTACGCAACCCGGGCCCCGAGTTGCATCAGC 2460
CGTTCGCAACCCGGGCTCCGAGTTGCATCAGCCGAAAGAAACTTCATTTCCCAAGCTT 2518
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Fig.4

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